

XVIII. *On the Heat of the Water in the Gulf-stream.* By
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Read April 26, 1781.

ONE of the most remarkable facts observed in navigating the ocean, is that constant and rapid current which flows along the coast of North America to the northward and eastward, and is commonly known to seamen by the name of the Gulf-stream. It seems justly attributed to the effect of the trade-winds, which blowing from the eastern quarter into the great Gulf of Mexico, cause there an accumulation of the water above the common level of the sea; in consequence of which, it is constantly running out by the channel where it finds least resistance, that is, through the Gulf of Florida, with such force as to continue a distinct stream to a very great distance. Since all ships going from Europe to any of the southern provinces of North America must cross this current, and are materially affected by it in their course, every circumstance of its motion becomes an object highly interesting to the seaman, as well as of great curiosity to the philosopher. An observation which occurred to me on the spot suggests a new method of investigating a matter that appears so worthy of attention.

During a voyage to America in the spring of the year 1776, I used frequently to examine the heat of sea-water newly drawn, in order to compare it with that of the air. We made our passage
3 far

far to the southward. In this situation, the greatest heat of the water which I observed was such as raised the quicksilver in FAHRENHEIT's thermometer to $77^{\circ}\frac{1}{2}$. This happened twice; the first time on the 10th of April, in latitude $21^{\circ} 10' N.$ and longitude, by our reckoning, $52^{\circ} W$; and the second time, three days afterwards, in latitude $22^{\circ} 7'$ and longitude 55° ; but in general the heat of the sea near the tropic of Cancer about the middle of April was from 76° to 77° .

The rendezvous appointed for the fleet being off Cape Fear, our course, on approaching the American coast, became north-westward. On the 23d * of April the heat of the sea was 74° , our latitude at noon $28^{\circ} 7' N.$ Next day the heat was only 71° ; we were then in latitude $29^{\circ} 12'$; the heat of the water, therefore, was now lessening very fast in proportion to the change of latitude. The 25th our latitude was $31^{\circ} 3'$; but though we had thus gone almost 2° farther to the northward, the heat of the sea was this day rather increased, it being 72° in the morning, and $72^{\circ}\frac{1}{2}$ in the evening. Next day, the 26th of April, at half after eight in the morning, I again plunged the thermometer into sea-water, and was greatly surprised to see the quicksilver rise to 78° , higher than I had ever observed it, even within the tropic. As the difference was too great to be imputed to any accidental variation, I immediately conceived that we must have come into the Gulf-stream, the water of which still retained great part of the heat that it had acquired in the torrid zone. This idea was confirmed by the subsequent regular and quick diminution of the heat: the ship's run for a quarter of an hour had lessened it 2° ; the thermometer,

* From the difference between civil and nautical time, it becomes necessary to observe, that the former is always meant in this paper.

at three quarters after eight, being raised by sea-water fresh drawn only to 76° ; by nine the heat was reduced to 73° , and in a quarter of an hour more, to 71° nearly: all this time the wind blew fresh, and we were going seven knots an hour on a north-western course. The water now began to lose the fine transparent blue colour of the Ocean, and to assume something of a greenish olive tinge, a well-known indication of soundings. Accordingly, between four and five in the afternoon ground was struck with the lead at the depth of eighty fathom, the heat of the sea being then reduced to 69° . In the course of the following night and next day, as we came into shallower water and nearer the land, the temperature of the sea gradually sunk to 65° , which was nearly that of the air at the time.

Unfortunately bad weather on the 26th prevented us from taking an observation of the sun; but on the 27th, though it was then cloudy at noon, we calculated the latitude from two altitudes, and found it to be $33^{\circ} 26' N$. The difference of this latitude from that which we had observed on the 25th, being $2^{\circ} 23'$, was so much greater than could be deduced from the ship's run marked in the log-book, as to convince the seamen that we had been set many miles to the northward by the current.

On the 25th at noon, the longitude by our reckoning was $74^{\circ} W$. and I believe the computation to have been pretty just; but the soundings, together with the latitude, will determine the spot where these observations were made better than any reckoning from the eastward. The ship's run on the 26th, from nine in the forenoon to four in the afternoon, was about ten leagues on a north-west by north course; soon afterwards

we hove-to in order to sound, and, finding bottom, we went very slowly all night, and till noon the next day.

From these observations, I think, it may be concluded, that the Gulf-stream, about the 33d degree of north latitude, and the 76th degree of longitude west of Greenwich, is, in the month of April, at least six degrees hotter than the water of the sea through which it runs. As the heat of the sea-water evidently began to increase in the evening of the 25th, and as the observations shew that we were getting out of the current when I first tried the heat in the morning of the 26th, it is most probable, that the ship's run during the night is nearly the breadth of the stream measured obliquely across; that, as it blew a fresh breeze, could not be much less than twenty-five leagues in fifteen hours, the distance of time between the two observations of the heat, and hence the breadth of the stream may be estimated at twenty leagues. The breadth of the Gulf of Florida, which evidently bounds the stream at its origin, appears by the charts to be two or three miles less than this, excluding the rocks and sand-banks which surround the Bahama Islands, and the shallow water that extends to a considerable distance from the Coast of Florida; and the correspondence of these measures is very remarkable, since the stream, from well-known principles of hydraulics, must gradually become wider as it gets to a greater distance from the channel by which it issues.

If the heat of the Gulf of Mexico was known, many curious calculations might be formed by comparing it with that of the current. The mean heat of Spanish-town and Kingston in Jamaica seems not to exceed 81° *; that of St. Domingo on

* History of Jamaica, London, 1774, vol. III. p. 652, 653. The different observations of the heat recorded in that work do not agree together; but those adopted here are taken from that series which appeared to me the most correct.

the sea-coast may be estimated at the same from *Monf. GODIN's* observations *; but as the coast of the continent which bounds the gulf to the westward and southward is probably warmer, perhaps a degree or two may be allowed for the mean temperature of the climate over the whole bay: let it be stated at 82° or 83° . Now there seems to be great probability in the supposition that the sea, at a certain comparatively small distance below its surface, agrees in heat pretty nearly with the average temperature of the air during the whole year in that part; and hence it may be conjectured, that the general heat of the water, as it issues out of the bay to form the stream, is about 82° †, the small variations of temperature on the surface not being sufficient to affect materially that of the general mass. At the tropic of Cancer I found the heat to be 77° ; the stream, therefore, in its whole course from the gulf of Florida, may be supposed to have been constantly running through water from 4° to 6° colder than itself, and yet it had lost only 4° of

* *Monf. GODIN's* experiments upon the pendulum were made at the Petit Goave. They continued from the 24th of August to the 4th of September, and the average heat during that time was such as is indicated by 25° of *Monf. DE REAUMUR's* thermometer (see *Mem. Acad. Scienc.* 1735, p. 517.). According to *Monf. DE LUC's* calculation (see *Modifications de l'Atmosphère*, vol. I. p. 378.) the 25th degree of *Monf. DE REAUMUR's* true thermometer answers to about the 85th of *FAHRENHEIT's*; but the average heat in Jamaica during the months of August and September is also 85° ; hence we may conclude, that the mean heat for the whole year is nearly the same on the sea-coasts in both islands.

† The lowest calculation of the mean temperature of the gulf is preferred on this occasion, because of the constant influx of new water from the Atlantic Ocean produced by the trade-winds; which water not having been near any land must, I think, be sensibly cooler than that which has remained some time inclosed in the bay. On this subject the observations made by *ALEXANDER DALRYMPLE, Esq.* relative to the heat of the sea near the Coast of Guinea, ought to be consulted (see *Phil. Trans.* vol. LXVIII, p. 394, &c.).

heat,

heat, though the surrounding water where I observed it was 10° below the supposed original temperature of the water which forms the current. From this small diminution of the heat, in a distance, probably of 300 miles, some idea may be acquired of the vast body of fluid which sets out of the gulf of Mexico, and of the great velocity of its motion. Numerous observations on the temperature of this stream, in every part of it, and at different seasons of the year, compared with the heat of the water in the surrounding seas, both within and without the tropic, would, I apprehend, be the best means of ascertaining its nature, and determining every material circumstance of its movement, especially if the effect of the current in pushing ships to the northward is carefully attended to, at the same time with the observations upon its heat,

On the 25th of September 1777, as the ships which had transported Sir WILLIAM HOWE's army up Chesapeake Bay were returning toward the Delaware, with the sick and stores, they were overtaken, between Cape Charles and Cape Hinlopen, by a violent gale of wind, which, after some variation, fixed ultimately at N.N.E. and continued five days without intermission. It blew so hard that we were constantly losing ground, and driving to the southward: we also purposely made some *easting* to keep clear of the dangerous shoals which lie off Cape Hatteras.

The 28th at noon our latitude was $36^{\circ} 40'$ N. and the heat of the sea all day about 65° . On the 29th our latitude was $36^{\circ} 2'$; we had, therefore, in the course of these twenty-four hours, been driven by the wind 38 nautical miles to the southward:

ward: the temperature of the sea continued nearly at 65° . Next day, the 30th, our latitude at noon was $35^{\circ} 44'$, only 18 miles farther to the southward, though in the opinion of the seamen aboard, as well as my own, it had blown at least as hard on this as any of the preceding days, and we had not been able to carry more sail; consequently it may be concluded, that some current had set the ship 20 miles to the northward. To know whether this was the Gulf-stream, let us consult the thermometer. At half after nine in the forenoon of this day the heat of this water was 76° , no less than *eleven* degrees above the temperature of the sea before we came into the current!

Towards evening the wind fell, and we stood N.W. by N. close-hauled. As the sea still ran very high, and the ship scarcely went above two knots an hour, we did not make less than three points of lee-way on this tack; the course we made good, therefore was W.N.W. which, on the distance run by noon next day, gave us about sixteen miles of *northing*; but that day, the 1st of October, our latitude was $36^{\circ} 22'$, 38 miles farther to the north than we had been the day before; the difference, 22 miles, must be attributed to the Gulf-stream. This, however, is only part of the effect which the current would have produced upon the ship if we had continued in it the whole four and twenty hours; for, though we were still in the stream at five in the afternoon of the 30th, as appeared by the heat of the water being then above 75° , and at eight in the evening the heat being still 74° , yet by seven next morning we were certainly got clear of it, the heat of the sea being then reduced to its former standard of 65° . On this occasion, therefore, we did not cross the stream, but having fallen-in with it obliquely

obliquely on the western side, we pushed out again on the same side as soon as the gale abated.

These observations having been made three degrees to the northward of my former ones, it is curious to observe, that the heat of the Gulf-stream was about 2° less. The seasons of the year, indeed, were very different; but, perhaps, under such circumstances that their effects were nearly balanced. In the latter observations the meridian altitude of the sun was less; but then a hot summer preceded them: whereas in the former, though the sun's power was become very great, yet the winter had been past but a short time. Calculating upon this proportion we may be led to suspect, that about the 27th degree of latitude, which is as soon as the stream has got clear of the gulf of Florida, it begins sensibly to lose its heat from 82° , the supposed temperature of the gulf of Mexico, and continues to lose it at the rate of about 2° of FAHRENHEIT's scale to every 3° of latitude, with some variation, probably as the surrounding sea, and the air, are warmer or colder at different seasons of the year.

The preceding facts had made me very desirous of observing the heat of the Gulf-stream on my passage homeward; but a violent gale of wind, which came on two days after we had sailed from Sandy Hook, disabled every person aboard, who knew how to handle a thermometer, from keeping the deck. The master of the ship, however, an intelligent man, to whom I had communicated my views, assured me, that on the second day of the gale the water felt to him remarkably warm; we were then near the 70th degree of west longitude. This agrees very well with the common remark of seamen, who alledge, that they are frequently sensible of the Gulf-stream off Nan-

tucket shoals, a distance of more than 1000 miles from the gulf of Florida! According to the calculation I have before adopted of a loss of two degrees of heat for every 3° of latitude, the temperature of the Gulf-stream here would be nearly 73°; the difference of which from 59°, the heat that I observed in the sea-water both before and after the gale, might easily be perceived by the master of the vessel. This was in the winter season, at the end of December.

An opinion prevails among seamen, that there is something peculiar in the weather about the Gulf-stream. As far as I could judge, the heat of the air was considerably increased by it, as might be expected; but whether to a degree or extent sufficient for producing any material changes in the atmosphere must be determined by future observations.

Perhaps other currents may be found which, issuing from places warmer or colder than the surrounding sea, differ from it in their temperature so much as to be discovered by the thermometer. Should there be many such, this instrument will come to be ranked among the most valuable at sea; as the difficulty of ascertaining currents is well known to be one of the greatest defects in the present art of navigation.

In the mean time, I hope the observations which have been here related are sufficient to prove, that in crossing the Gulf-stream very essential advantages may be derived from the use of the thermometer: for if the master of a ship, bound to any of the southern provinces of North America, will be careful to try the heat of the sea frequently, he must discover very accurately his entrance into the Gulf-stream, by the sudden increase of the heat; and a continuance of the same experiments will shew him, with equal exactness, how long he remains in it. Hence he will always be able to make a proper allowance

for the number of miles that the ship is set to the northward, by multiplying the time into the velocity of the current. Though this velocity is hitherto very imperfectly known, for want of some method of determining how long the current acted upon the ships, yet all uncertainty arising from thence must soon cease, as a few experiments upon the heat of the stream, compared with the ship's run checked by observations of the latitude, will ascertain its motion with sufficient precision. From differences in the wind, and perhaps other circumstances, it is probable, that there may be some variations in the velocity of the current; and it will be curious to observe, whether these variations may not frequently be pointed out by a difference in its temperature; as the quicker the current moves, the less heat is likely to be lost, and consequently the hotter will the water be. In this observation, however, the season of the year must always be considered; partly, because it may, perhaps, in some degree affect the original temperature of the water in the gulf of Mexico; but principally, because the actual heat of the stream must be greater or less in proportion as the tract of the sea through which it has flown was warmer or colder. In winter, I should suppose, that the heat of the stream itself would be rather less than in summer; but that the difference between it and the surrounding sea would be much greater; and I can conceive that, in the middle of summer, though the stream had lost very little of its original heat, yet the sea might, in some parts, acquire so nearly the same temperature, as to render it scarcely possible to distinguish by the thermometer when a ship entered into the current.

Besides the convenience of correcting a ship's course, by knowing how to make a proper allowance for the distance she is set to the northward by the current, a method of determining

with certainty when she enters into the Gulf-stream is attended with the further inestimable advantage of shewing her place upon the ocean in the most critical situation: for, as the current sets along the coast of America at no great distance from foundings, the mariner, when he finds this sudden increase of heat in the sea, will be warned of his approach to the coast, and will thus have timely notice to take the necessary precautions for the security of his vessel. As the course of the Gulf-stream comes more to be accurately known, from repeated observations of the heat and latitudes, this method of determining the ship's place will be proportionably more applicable to use. And it derives additional importance from the peculiar circumstances of the American coast, which, from the mouth of the Delaware to the southernmost point of Florida, is every where low, and beset with frequent shoals, running out so far into the sea that a vessel may be aground in many places where the shore is not to be distinguished even from the mast-head. The gulf-stream, therefore, which has hitherto served only to increase the perplexities of seamen, will now, if these observations are found to be just in practice, become one of the chief means of their preservation upon that dangerous coast.

